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On pricing algorithms for batched content delivery systems

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Abstract

Businesses offering video-on-demand (VoD) and downloadable-CD sales are growing in the Internet. Batching of requests coupled with a one-to-many delivery mechanism such as multicast can increase scalability and efficiency. There is very little insight into pricing such services in a manner that utilizes network and system resources efficiently while also maximizing the expectation of revenue. In this paper, we investigate simple, yet effective mechanisms to price content in a batching context. We observe that if customer behavior is well understood and temporally invariant, a fixed pricing scheme can maximize expectation of revenue if there are infinite resources. However, with constrained resources and potentially unknown customer behavior, only a dynamic pricing algorithm can maximize expectation of revenue. We formulate the problem of pricing as a constrained optimization problem and show that maximizing the expectation of revenue can be intractable even when the customer behavior is well known. Since customer behavior is unlikely to be well known in an Internet setting, we develop a model to understand customer behavior online and a pricing algorithm based on this model. Using simulations, we characterize the performance of this algorithm and other simple and deployable pricing schemes under different customer behavior and system load profiles. Based on our work, we propose a pricing scheme that combines the best features of the different pricing schemes and analyze its performance.

Keywords: e-Content; Batching; Customer behavior; Price; Dynamic pricing

1. Introduction

The Internet is seeing an explosive growth in commercial activities. Downloadable software and multimedia are especially popular. One can think of scenarios where customers can download music, movies, and even books after online transactions. Video-on-Demand (VoD) is one such service in the Internet. However, in spite of the immense research interest in VoD over the last decade [1–5], commercial efforts have failed to materialize. One of the possible reasons why they have failed until now is the lack of a good business model. Given the renewed interest in such services, it is very important to develop a sound business model.

When the content is popular, and user interactivity is not required, using multicast [6,7] or broadcast [8] mechanisms to serve many users simultaneously

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improves scalability of the system. This is accomplished by a technique known as *batching*. Requests for the same content are aggregated over a period of time and then served in one single transmission using a one-to-many delivery mechanism such as multicast or broadcast. This benefits the content provider greatly because fewer resources are utilized at the cost of a small waiting time for the customers. In this paper, using analysis and heuristics, we develop a business model for systems implementing batching for content distribution. In our earlier work [9–11], we have developed pricing models for systems that do not implement batching.

Pricing must take into account customer valuations as well as resource constraints. Let us consider an illustrative example. Consider a content provider selling downloadable CDs. The number of CDs that can be downloaded from the web site within a given time frame is limited by the bandwidth and server resources available. Furthermore, the resources available cannot be arbitrarily increased. This is because, the demand (or request arrival process) in an Internet setting may not be easily predictable. For instance, a very exclusive and popular music album available at the web-site may increase demand for a short period of time, say a fortnight. Once the initial popularity wanes, demand (and hence request arrival rate) will drop. Long-term investments in high capacity links and server resources to meet the demand may therefore not be a practical solution. At the same time, short-term acquisition of server resources and bandwidth may not be possible. In such a situation, two questions arise: (1) can the content provider increase revenues during the peak times by serving the same number of customers for a higher price? and (2) can the content provider reduce the number of customers denied service[1] during peak times by charging a higher rate for the service? These are interesting questions that need to be answered for successful deployment and acceptance of content distribution networks by the commercial world.

Our objective in this paper is to answer the above questions by constructing a formal model for pricing content in a system with dynamic load patterns. To develop a thorough understanding of the fundamental problem area, we limit our considerations in this paper to a rudimentary, yet practically relevant, content delivery architecture. Our work presents essential findings, which provide the foundation for future extensions towards more complex scenarios. Even so, there are various choices for pricing the content: subscription-based pricing, quoted-price, sealed-bid auctions, etc. In this work, we restrict ourselves to a quoted-price model, wherein the content provider quotes a price to the customer. The customer may accept or reject the service based on his/her valuation of the service. We observe that if customer behavior is time invariant and well known, then a strategy of charging a fixed price can maximize the expectation of revenue if there are infinite distribution resources. When resources are constrained, fixed pricing may not maximize expectation of revenue. Nevertheless, there is usually a strong case for a fixed price because it is simple to implement. In this work, our goal is to explore the benefits of a dynamic pricing structure. We believe that subscription-based pricing coupled with a dynamic pricing scheme can address most customers' concerns. Risk-averse customers can opt for the subscription pricing while other customers can opt for the quoted-price model. Since requests are batched, subscribers' requests will not compete for resources with the quoted-price model customers.

We formulate the problem of pricing in a batching system as a constrained optimization problem. We show that for some kinds of customer behavior, even when that behavior is well known, the problem of maximizing the expectation of revenue is intractable. In reality, customer behavior cannot be accurately known.[2] We propose a framework to understand customer behavior parameters in such a situation. Using this framework, we develop a pricing algorithm. We also study other simple, yet effective pricing schemes[3] that can be adopted in a content

[1] We make a distinction between customers who are denied service because they do not accept the price and those who accept the price but are denied service due to resource constraints.

[2] Market surveys usually provide some information. However, they are costly and have potentially limited accuracy in a dynamic environment like the Internet.

[3] All the pricing schemes discussed in the paper conform to the quoted-price model, where the content provider quotes a price to the customer.